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To Mr. F.J. Kee
Director of Research

PCB REMOVAL - SILICONE FILLED TRANSFORMERS

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Two commercial carbon adsorbent systems, one employing bagged, granular carbon and the other powdered carbon impregnated on a fibrous support medium, were used to remove polychlorinated biphenyls (PCBs) from silicone fluid in two 300 kVA, 560 L capacity transformers. Contamination of 4000-4200 mg PCB/kg silicone fluid was reduced to less than 50 mg/kg with approximately 16 kg of carbon applied in 1.5-2 kg adsorbent charges. The powdered carbon system tested is considered acceptable for field use but not for transformers containing more than about 200 g PCB due to high adsorbent replacement costs. The granular system is not hardy enough for field use,however, and design changes to incorporate a manifold of adsorbent charges are required to reduce operator labour. Decontamination costs are estimated at $4,000-$4,500 per transformer.

INTRODUCTION

In June, 1981 the Chemical Research Department tested a procedure to replace transformer askarel[1] in large transformers with polydimethylsiloxane (silicone) fluid. Unlike askarel, silicone fluid contains no polychlorinated biphenyls (PCBs) and an askarel transformer refilled with silicone fluid is not considered an environmental hazard, provided the residual PCB contamination of the fluid does not exceed 50 mg/kg.

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1 Askarel is a generic term for blends of polychlorinated biphenyls and tri-and tetrachlorinated benzenes.

job	file	date	report no.
7406632-456-590	832.733	June 1, 1984	84-114-K

The fluid replacement procedure consisted of a 24 h drain period followed by two successive flushes with hot trichloroethylene and a refill with silicone fluid. It was applied to two 300 kVA transformers and successfully removed askarel from drainable areas and exposed surfaces. However, some PCBs remained in transformer internals and PCB contamination of the bulk of the silicone refill fluid gradually increased to about 4 000 mg/kg due to leaching.

Because fluids or equipment contaminated with more than 50 mg/kg PCBs are considered as PCB hazards by Ontario Regulation 11/82 under the Environmental Protection Act, the work described in this report was undertaken to determine if it was practical to reduce residual PCB contamination in the silicone dielectric of the two transformers to less than 50 mg/kg by a carbon bed adsorption method.

EXPERIMENTAL

Transformers

The transformers under test are 3-phase, 300 kVA units, each weighing approximately 2600 kg when filled with about 560 L of Dow Corning DC-561 silicone electrical insulating fluid. These 20 year old units are identified by serial numbers 3551-2T (Pioneer) and 2-91625 (Ferranti-Packard) and are on loan from Head Office and Kipling Facilities Department, Real Estate Services Division, for this test program.

The units were filled with silicone fluid in June, 1981 and energized for approximately 1000 h beginning in August, 1981. The PCB content of the silicone fluid averaged 2000 mg/kg immediately following the filling procedure and 4100 mg/kg sixteen months later.

Adsorption Systems

Based on a previous study/1/, which concluded that granular carbon could remove PCBs from contaminated silicone fluid without significantly affecting the electrical or physical characteristics of the fluid, two carbon adsorption systems were selected for test. One was a granular carbon adsorption system, the "Infiltrator PMDC3" manufactured by Sethco Corporation and designed to remove organic materials from aqueous process streams. The other was a powdered carbon system for oil reconditioning manufacturered by Peacock Incorporated. The Peacock unit uses a proprietary "Zeta Plus" carbon media.

A third system, manufacturered by Dow Corning, was considered but was not commercially available at the start of the test program. This unit utilizes a granular carbon adsorbent/2/.

Cross-section drawings and some operating data for the Sethco and Peacock adsorption systems are given in Appendix 1.

Adsorption Process

With both test systems, PCB decontamination of transformer fluid was accomplished by cycling the fluid through a sequence of adsorbent charges until the PCB concentration was reduced to less than 50 mg/kg. The need for adsorbent charge exchange was indicated by a marked decrease in the rate of PCB removal from the fluid.

Prior to use on transformers the adsorption systems were tested on a 100 L volume of 300 mg/kg PCB contaminated silicone fluid. This provided an opportunity to check out system operation and develop a method for carbon charge conditioning (removal of carbon fines).

Conditioning and decontamination procedures are described in Appendix 2.

RESULTS AND DISCUSSION

Adsorption Data

In the checkout and conditioning tests each carbon system reduced PCB contamination in 100 L of silicone fluid from an initial 300 mg/kg to a final <50 mg/kg. The Sethco system required two 1.5 kg granular carbon charges and the Peacock system required one 2 kg powdered carbon charge[2] to effect the PCB removal.

On startup, both adsorption systems released enough carbon fines to darken the insulating fluid. However, after less than 2 h of recirculation the fluid was clear and the carbon content measured less than 1 mg/kg.

The units were considered acceptable for use on the PCB contaminated transformers on the basis of the above test results.

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[2] This weight of powdered carbon is impregnated on three separate fibrous adsorbent cartridges in the unit.

PCB concentration data obtained during decontamination of the two silicone retrofilled transformers are given in Tables I and II. The following are noted:

1. At PCB concentrations between 100 and 4000 mg/kg, the silicone dielectric fluid reached equilibrium with the Sethco adsorption system within 25 h. As PCB concentrations fell significantly below 1000 mg/kg the equilibrium time rapidly increased to several hundred hours (Table I).

   Equilibrium with the Peacock powdered carbon adsorbent system and its much larger surface area was achieved in less than 25 h at PCB concentrations above about 500 mg/kg. However, up to several hundred hours of adsorption were required at lower concentrations (Table II).

2. As expected based on the laboratory studies of Reference 1, the adsorption capacity of a new carbon charge rapidly decreased as the PCB content of the fluid to be filtered decreased.

3. Ten 1.5 kg carbon charges were required to reduce the PCB content of silicone fluid from an initial 4200 mg/kg to a final 45 mg/kg in transformer SN2-91625 using the Sethco adsorption system. Fifty-seven percent of the PCB removal occurred during the first 2 charges.

4. Seven 2 kg carbon charges were required to reduce the PCB content of silicone fluid from an initial 4000 mg/kg to a final 90 mg/kg in transformer SN3551-2T using the Peacock adsorption system. One additional 1.5 kg charge using the Sethco system was required to obtain a final concentration of 45 mg/kg. Fifty-six percent of the PCB removal occurred during the first 2 charges.

Adsorption Capacity

The relative effectiveness of the two carbon adsorption systems can be assessed by comparing adsorption characteristics derived from the Freundlich adsorption isotherm/3/:

$$X/M = K\ (C_f)^{1/n} \qquad (1)$$

where X/M is the concentration of PCB on the carbon, C_f is the concentration of PCB in the treated silicone fluid, and K and 1/n are constants. For data represented by this formula a log-log plot of (X/M) vs C_f is a straight line with slope (1/n) and intercept log(K).

TABLE I

PCB CONTENT OF SILICONE FLUID IN TRANSFORMER SN 2-91625 DURING ADSORPTION TEST*
(mg PCB/kg fluid)

Cycling Time (h)	Carbon Charge Number (in order of use)									
	1	2	3	4	5	6	7	8	9	10
0	4200	3300	2500	1800	1300	900	480	270	160	100
25	3300	2500	1900	1300	1100	620	370	NA	NA	NA
50	3300	2500	1800		NA[1]	NA	NA	NA	NA	NA
75	3300	NA			NA	NA	NA	NA	NA	NA
100		NA			900	NA	NA	170	NA	NA
125		2500				530	290	NA	NA	NA
150		2500				510	NA	NA	100	45
300						480	NA	NA		
400							NA	160		
450							270			

* Sethco adsorption system as shown in Appendix 1.

[1]NA = not analyzed

TABLE II

PCB CONTENT OF SILICONE FLUID IN TRANSFORMER
SN 3551-2T DURING ADSORPTION TEST*
(mg PCB/kg Fluid)

Cycling Time (h)	Carbon Charge Number (in order of use)							
	1	2	3	4	5	6	7	8**
0	4000	2500	1770	960	520	400	240	90
25	2700	1770	960	510	390	NA[1]	NA	NA
50	2600	NA	970	520	400	NA	NA	40
75	NA	1770	960			NA	NA	
125	2500					NA	NA	
175						240	NA	
200							90	

* Peacock Adsorption System as shown in Appendix 1 was used for adsorption charges 1-7.

** Sethco adsorbent used for adsorption charge 8.

[1]NA = not analyzed

Freundlich plots of the data in Tables I and II, and the values of the parameters K and (1/n) determined from these plots, are compared with "reference" data for granular carbon in Figure 1 and Table III, respectively.

TABLE III

FREUNDLICH CONSTANTS FOR TEST ADSORPTION SYSTEMS

Curve Number (Figure 1)	System Description	K x 10^3*	1/n	Correlation Coefficient
1**	Sethco -1.5 kg granular carbon per charge	1.55	0.669	0.996
2**	Peacock -2 kg powdered carbon per charge	1.40	0.702	0.953
3	Lab test-10 g granular carbon per charge/1/	4.60	0.711	0.998

* K and 1/n are dimensionless constants used in relation (1) of text.

** Data points underlined on Figure 1 were excluded from the linear least-squares calculation used to determine the Freundlich constants due to uncertainties in PCB concentrations and suspected channelling effects.

The adsorption capacities of the carbons used in the Sethco and Peacock systems are almost identical, as shown by the closely spaced plots of Figure 1 and the similar values for the Freundlich constants of Table III.

The relatively high scatter observed in the data for the Peacock system is probably due to mixing of decontaminated and contaminated fluid in the transformer as a result of the system's high flow rate. For efficient decontamination, flow rates must be kept low to maintain plug flow and minimize the recycling of decontaminated fluid.

The reference curve 3 of Figure 1 was obtained from laboratory data for a series of adsorption tests using pure PCB (arochlor

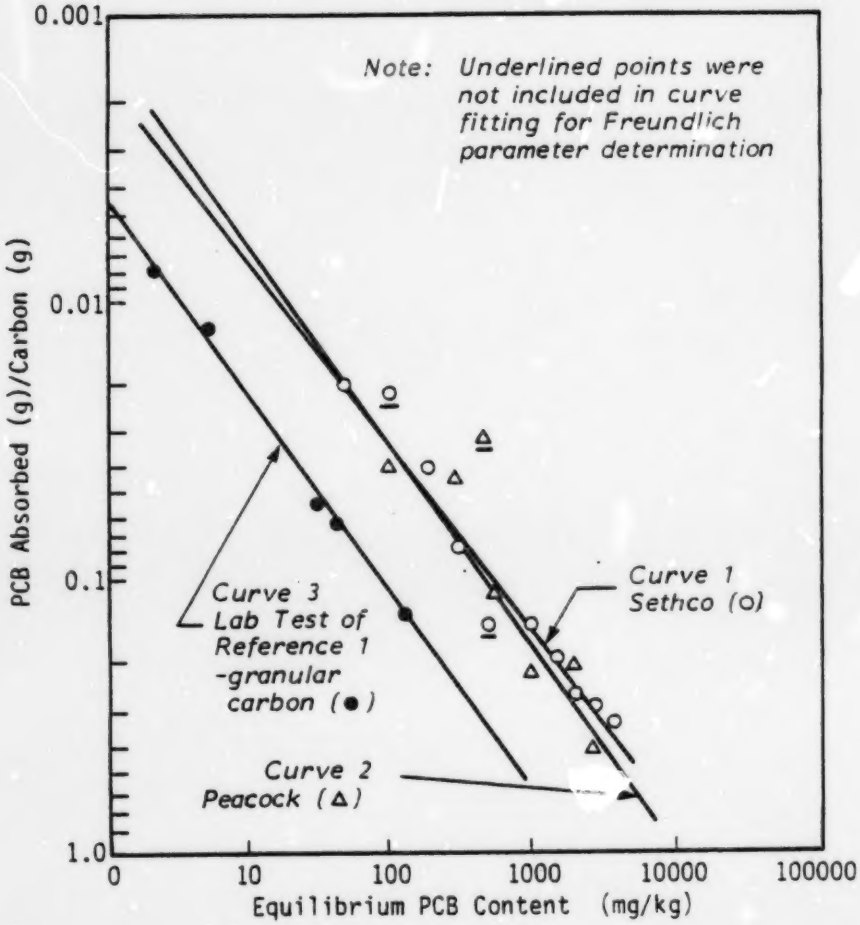

FIGURE 1

FREUNDLICH PLOTS FOR TEST AND REFERENCE CARBONS

1254), and the same carbon type (Westvaco WV-G) as used in the Sethco tests. The PCB adsorption capacity in the laboratory test is estimated as about three times that observed during transformer decontamination.

The discrepancy between the reference and test curves is partially explained by the fact that carbon removes tri- and tetra-chlorinated benzenes (T/TCB) and not only PCBs from askarel contaminated silicone fluid/1/. Over the course of the decontamination project the test adsorbents reduced the T/TCB content from an initial average of 2800 mg/kg to a final <50 mg/kg.

The adsorption of T/TCB by the carbon accounts for about one-half the discrepancy between the test curves and reference curve of Figure 3, under the assumption that the T/TCB competes with PCB for a fixed number of adsorption sites. The respective average molecular weights for the T/TCB and PCB components of the transformer askarel of this study are 180 and 325, respectively, and therefore the T/TCB component may occupy about (325/180) times as many carbon sites per unit weight as does PCB. On an occupied site basis, the 2800 mg/kg T/TCB is equivalent to 5000 mg/kg PCB contamination.

Trichloroethylene (TCE) was present in the silicone fluid at an initial concentration of approximately 40 000 mg/kg as a consequence of transformer rinsing procedures prior to silicone fluid refill. Because PCBs and T/TCBs were removed by carbon in spite of the large quantity of TCE in the silicone fluid it is clear that TCE does not seriously compete with PCBs or T/TCBs for carbon adsorption sites. However, it is suspected that enough TCE is present to increase the affinity of the silicone fluid for PCBs and T/TCBs and so decrease the adsorption capacity of the carbon adsorbent for these materials. As the presence of TCE in the silicone fluid was unexpected, further work is required to determine its influence on adsorption in carbon/silicone fluid systems.

Problems with Carbon Adsorbent Test Systems

Although the Sethco adsorption unit accomplished the decontamination task, several aspects of its design made it unsuitable for use without major modifications. A magnetically coupled fluid drive pump did not deliver the required flow through the unit and had to be replaced with a positive displacement gear pump. O-ring seals leaked, carbon bag removal was difficult and two hose connectors on the carbon containment chamber broke during normal use.

The Peacock system performed well in use; however, carbon exchange was inconvenient as the outer shell of the carbon charge housing is not sealed to the housing base plate and therefore considerable PCB contaminated silicone fluid escaped into the unit's spill tray during adsorbent exchange.

Neither unit was equipped with a recirculation loop to aid in carbon fines removal prior to use on transformers and therefore recirculation was accomplished by linking input and output hoses through a separate silicone fluid reservoir.

Transformer Decontamination Costs

Although the decontamination techniques used in this project were experimental and therefore not optimized for minimum material use, adsorption time or operator involvement, the decontamination costs can probably be taken as high estimates for field operation under similar circumstances. A summary of the costs associated with each transformer decontamination is given in Table IV.

In addition to anticipated costs such as for carbon, operation labour and extra silicone fluid to replace that lost by absorption on carbon, unexpected but significant costs were incurred in extensive system decontamination after test and in the repair of leaking transformer gaskets not compatible with silicone fluid.

A cost tradeoff between the two test systems is evident from Table IV. The high labour cost of the Sethco system is offset by the high carbon cost of the Peacock system.

Because efficient PCB removal requires successive application of new carbon adsorbent, operator labour might be considerably reduced by manifolding several carbon charge canisters in a single adsorption system. Carbon changes could then be made by switching charge-select valves. In addition, carbon removal and conditioning need not take place at the transformer site and could be performed on all carbon charges at one time. Such systems might reduce operating labour by about 75 per cent based on time estimates for the repetitive tasks eliminated by manifolding.

Firm data for the cost of storage and disposal of PCB contaminated carbon and associated materials are not available at present as no disposal route for these materials has been approved by the provincial Minstry of the Environment. Based on PCB incineration costs in other countries, the disposal cost for wastes generated in silicone fluid decontamination procedures is estimated to be at least $3.00/kg waste if incineration of PCB wastes is eventually allowed.

TABLE IV

OPERATING COST SUMMARY

PCB REMOVAL FROM CONTAMINATED SILICONE FLUID FILLED TRANSFORMERS

Cost Item	Cost	
	Ferranti-Packard* SN 2-91625	Pioneer ** SN 3551-2T
Carbon	85.00	2100.00
Silicone Fluid Loss	105.00	205.00
Viton Gaskets	100.00	100.00
Gasket Replacement Labour	1000.00	1000.00
Operator Labour	2500.00	925.00
Cleanup Labour and Materials	200.00	200.00
Total	3980.00	4530.00

* Sethco system used exclusively for 10 adsorption cycles.

** Peacock system used for 7 of 8 adsorption cycles, Sethco System used for last cycle.

Adsorption System for Field Use

A simple manifolded system which might be considered for routine decontamination of silicone filled transformers is shown in Figure 2.

Major operating steps are as follows:

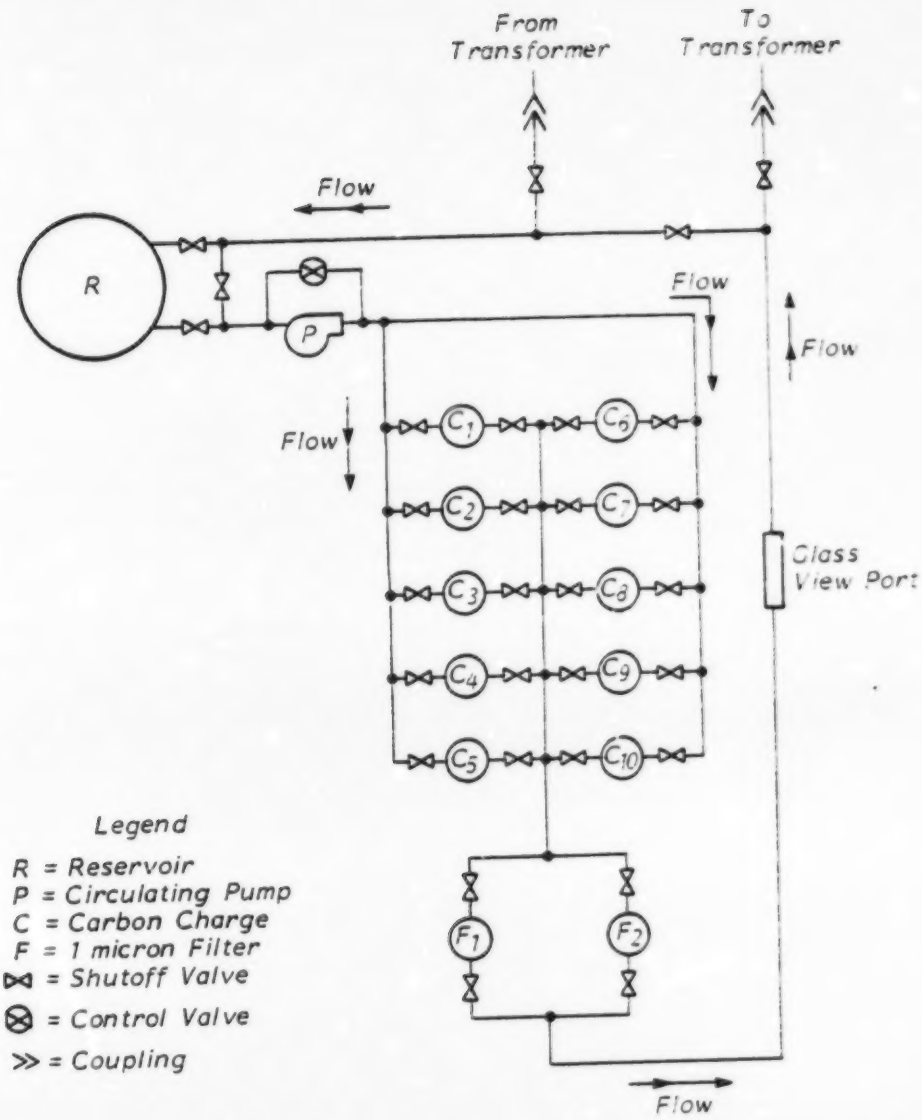

FIGURE 2
MANIFOLDED CARBON ADSORPTION SYSTEM FOR
PCB REMOVAL FROM SILICONE FLUID

1. Granular 0.18 cm x 0.04 cm (12 x 40 mesh) carbon, pre-packaged in fine mesh bags, is loaded into the carbon charge housings, C, and silicone fluid from the reservoir, R, is cycled through each charge in sequence until no carbon is visible in the cycling fluid.

2. The decontamination unit is attached to the transformer, the reservoir is removed from the circuit and the silicone fluid from the transformer is cycled through the first carbon charge.

3. Every 24-48 h a new carbon charge is switched into the circuit and a spent carbon charge is switched out.

4. Unloading of spent carbon is performed once all charges have been exhausted.

CONCLUSIONS

1. PCB contaminated, silicone fluid filled transformers can be decontaminated to less than 50 mg PCB/kg fluid by either granular or powdered carbon systems. The PCB is removed by adsorption on carbon and the relationship between PCB concentration and carbon capacity is given by the Freundlich adsorption isotherm.

2. The Peacock adsorption system used in the test program is suitable for field service although the high cost of carbon replacement charges may restrict its use to transformers with low PCB concentrations (<300 mg/kg). The Sethco unit tested is not robust enough for field use.

3. Neither adsorption system tested is convenient to use due to the lack of fluid recirculation loops and problems associated with removing PCB contaminated carbon charges.

4. Granular or powdered carbon charges of the size used in this test program are for practical purposes exhausted after 24-48 h of fluid cycling. Full capacity is not achieved until cycling is continued for hundreds of hours.

5. Approximately 1 kg of PCB contaminated carbon is produced for every 35 L of silicone fluid decontaminated from an initial 4100 mg PCB/kg to a final <50 mg PCB/kg.

6. The cost of decontaminating a silicone fluid filled transformer containing approximately 4000 mg/kg PCB in 560 L of fluid is about $4000.00, excluding decontamination equipment capital cost. A granular carbon adsorption system

consisting of about ten 1.5 kg carbon charges manifolded in parallel could be used more efficiently than either of the tested systems and might reduce the operating costs by as much as $1900.00 per unit (1983 $).

RECOMMENDATIONS

1. The decontaminated transformers should be put under load and the PCB content of the silicone fluid monitored at monthly intervals to determine if further PCB leaching from the core occurs.

2. The Peacock adsorption system used in this study, or equivalent, is recommended for PCB removal from silicone fluid provided that the initial quantity ot PCB in the fluid is less than about 200 g. For larger quantities of PCB a manifolded granular carbon adsorption system should be considered.

Approved:

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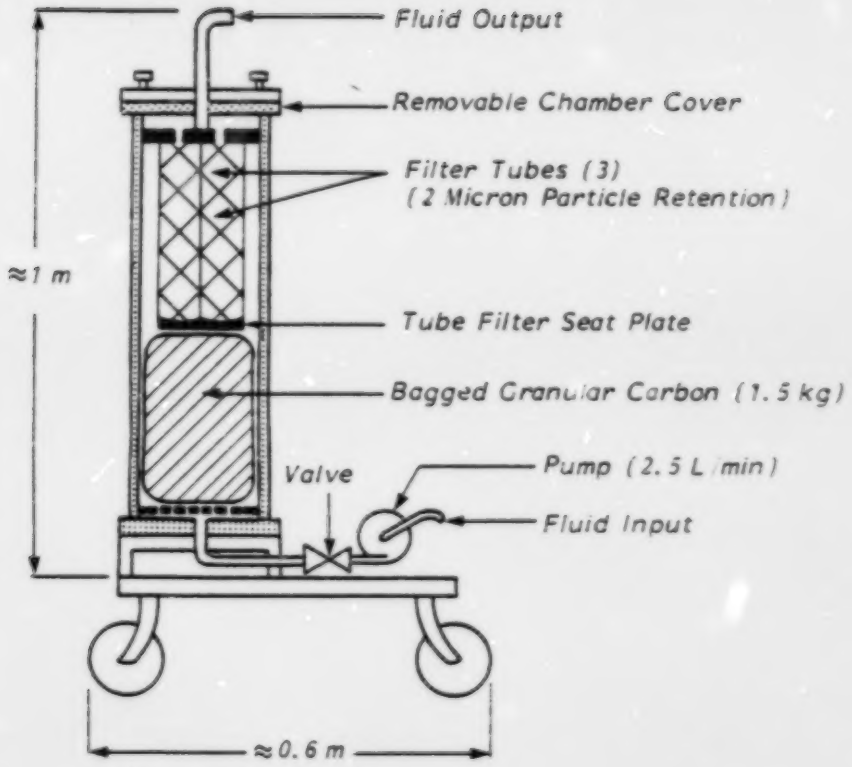
REFERENCES

1. Janis, W.J., "PCB Removal From Silicone Insulating Fluid", Research Report 82-34-H, (February, 1982).

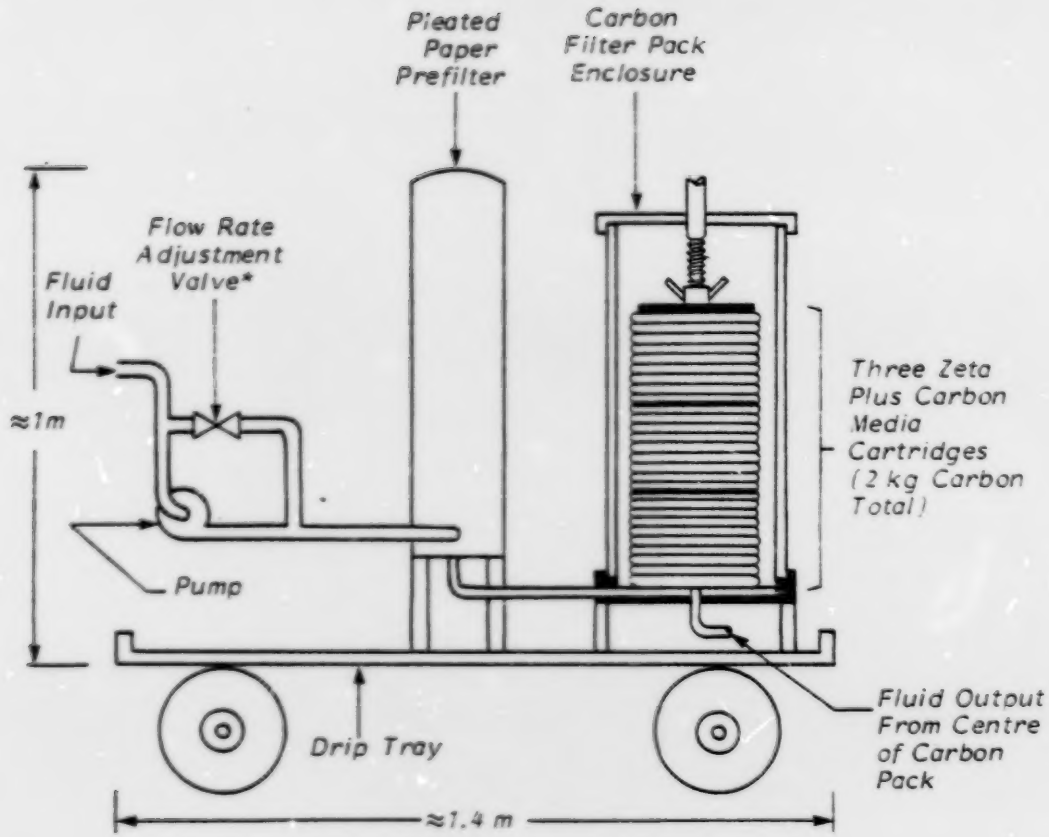
2. Anon., "PCB Clean-Up Unit Aids Silicone Retrofills of Transformers", Transmission and Distribution, p 16, (October,1982).

3. Anon., "Measuring Adsorptive Capacity of Activated Carbons", Technical Bulletin D-87, ICI (US) Inc, (1963).



APPENDIX 1

(a) SETHCO INFILTRATOR PMDC3



* Flow Rate Adjusted to 10L/minute

APPENDIX 1 (CONTINUED)

(b) PEACOCK OIL CONDITIONING SYSTEM

APPENDIX 2

ADSORPTION PROCESSES

(a) Sethco System

The Sethco adsorption system was used exclusively to decontaminate the Ferranti-Packard transformer as follows:

1. One and one-half kilograms of 0.18 cm x 0.04 cm (12 x 40 mesh) coal based, granular carbon in a fine mesh bag were placed in the carbon charge canister.

2. Twenty litres of silicone fluid were circulated through the cannister until the output fluid was clear. During this cycling, carbon fines were removed from the fluid by 3 µm pore size, wound nylon filament, cartridge filters in series with the carbon charge.

3. System input was connected to the drain valve of the transformer and the return line was placed in the manhole opening in the top of the transformer.

4. The transformer fluid was cycled through the system at approximately 2.5 L/min for several days until the PCB content of the fluid did not change significantly.

5. Steps 1-4 were repeated until the 50 mg/kg PCB limit was achieved.

(b) Peacock System

The Peacock adsorption system was used to reduce the PCB content of the Pioneer transformer to 90 mg/kg, at which time the Sethco unit was substituted for reasons of cost. The procedure was similar to that used with the Sethco system with the following exceptions:

1. Three powdered-carbon impregnated paper cartridges containing a total of 2 kg carbon were used in place of granular carbon.

2. The flow rate was approximately 10 L/min.